Validation of the CERES Ed4 & Ed2 Arctic Cloud Properties using DOE ARM NSA Ground-Based Retrievals

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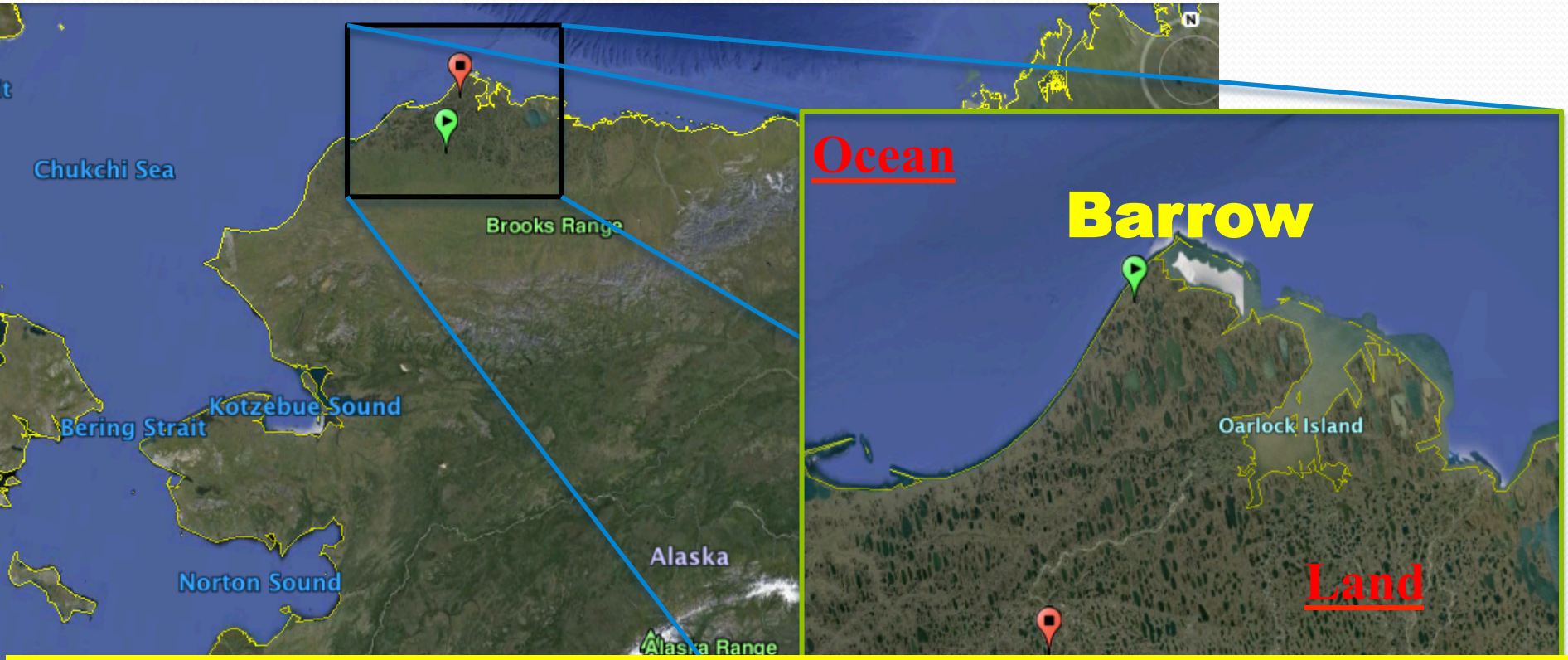
Location of ARM Northern Slope of Alaska (NSA Site)



Clouds at ARM NSA site represent typical Arctic clouds with cloud fraction ~ 80%.

A grid box (100 km x 100 km) includes half ocean and half land surface.

Low cloud microphysical properties (re/tau/LWP) over open water and land during Summer months are compared.

Challenges for Satellite cloud retrievals

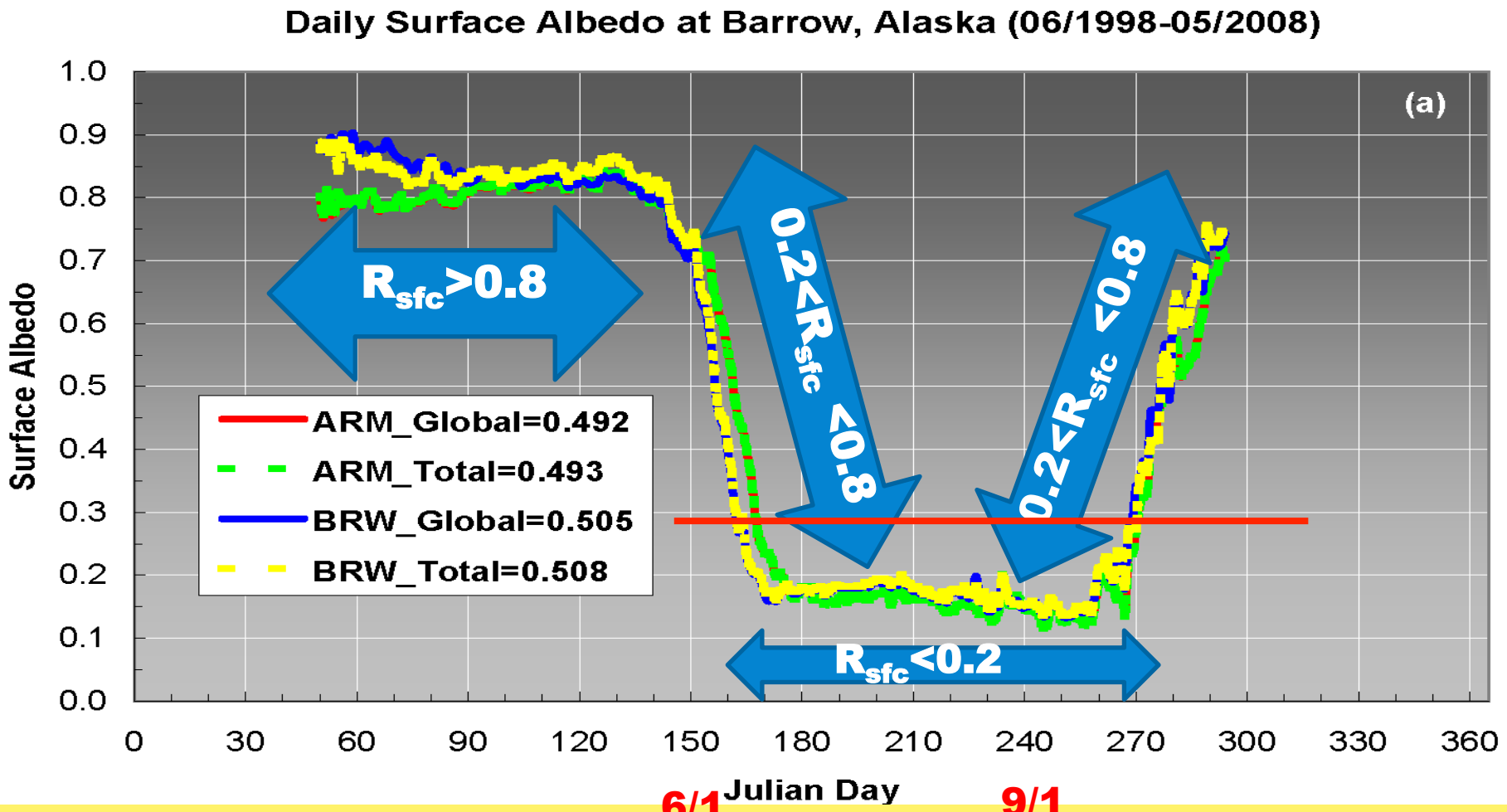
Can passive satellites accurately retrieve Arctic cloud microphysical properties under the conditions of

1) no snow/ice covered surfaces (R_{sfc}<0.3)? If so, do they agree with the ground-based retrievals?

2) highly reflecting snow/ice covered surfaces (R_{sfc}>0.3) from October to early June?

3) Do the satellite retrievals change with surface albedos and solar zenith angles?

Seasonal variation of daily surface albedo



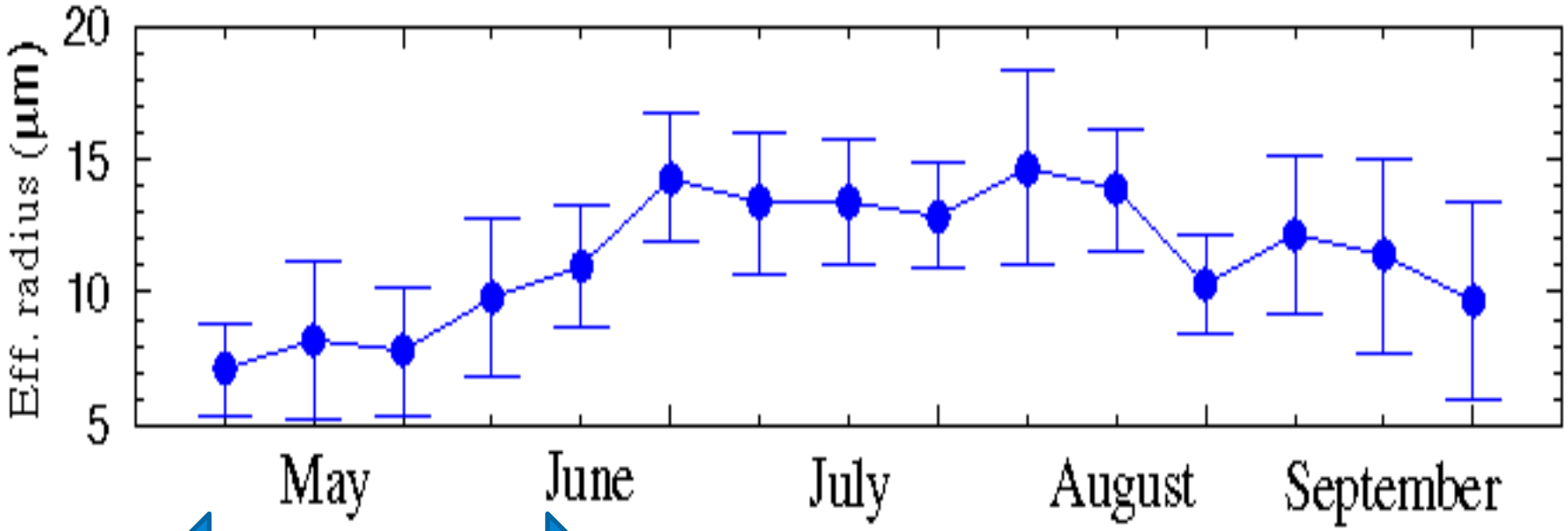
- **Snowmelt occurred from late May to early June**
- **R_{sfc}≥ 0.3→ snow/ice period**
- **R_{sfc}< 0.3 → no snow from middle June to late Sept.**
- **CERES uses monthly albedo maps w/out snow, it may lead to some errors in cloud retrievals during transition seasons.**

Datasets and Goal

1) Only single-layered overcast low clouds with liquid or liquid dominant mixed-phase clouds have been selected under NO snow (surface albedo<0.3) and snow (R_{SFC}>0.3) conditions.
2) Only cloud microphysical properties, such as re, tau, and LWP, are compared in this study over the ARM NSA site
3) Time period: March 2000 to December 2006
4) A total of 701 samples selected during studying period including 404 samples without snow and 297 samples under snow condition.

The goal of this study will partially answer three questions posed in the beginning.

Retrieved low-level cloud-droplet effective radius from ARM NSA measurements and RTM (Dong and Mace, 2003, J Clim.)



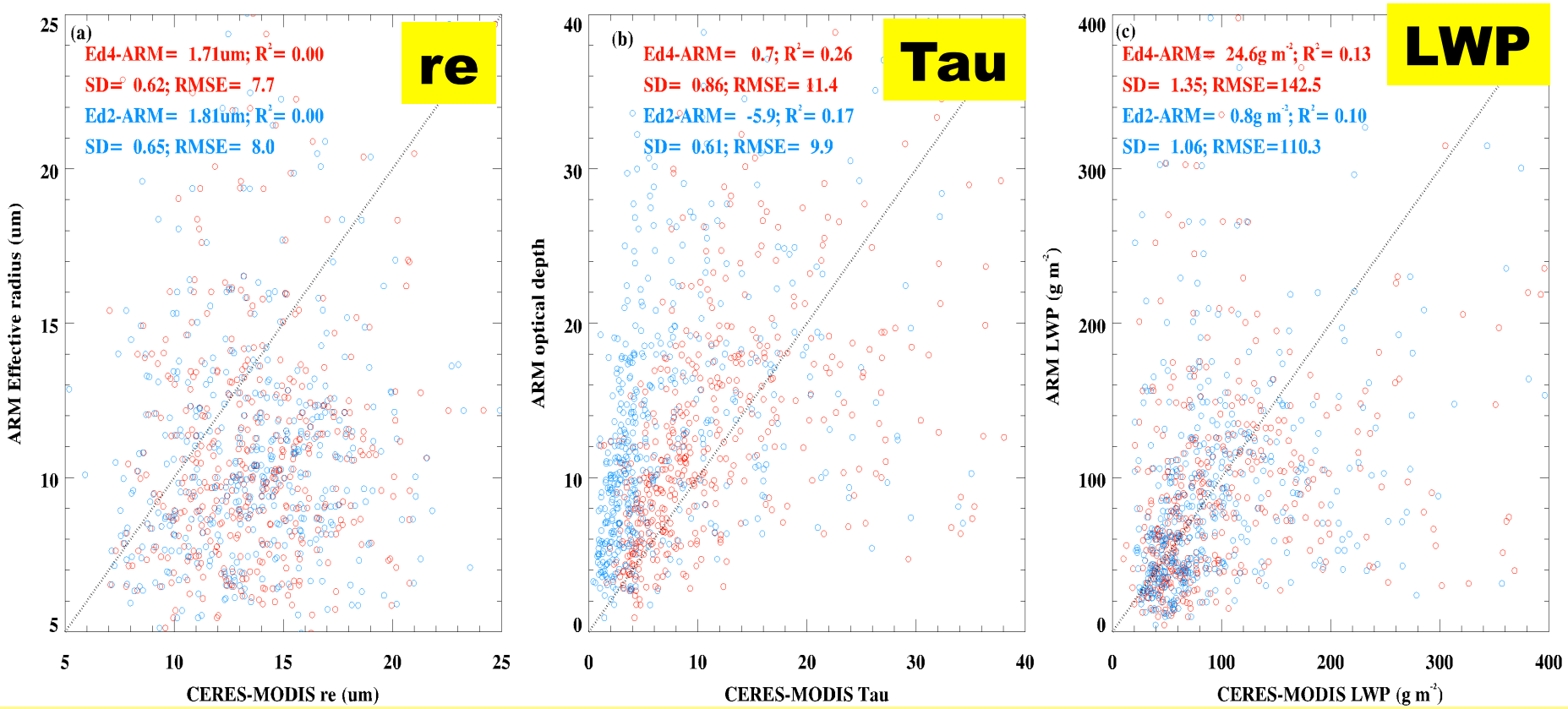
- During the snow/ice covered periods, r_e~ 7-10 um, close to r_e at the ARM SGP site (continental)
- During summer, r_e~ 13 um, close to r_e at the ARM Azores site (MBL).
- These retrievals were compared with in-situ data during SHEBA and M-PACE.

Objective 1 (No Snow)

Based on 404 selected samples (No snow), we want to know

1) Any improvements of CERES Ed4 derived cloud microphysical properties (re, tau, LWP) compared to Ed2 over NO snow/ice covered surfaces (Ocean side and land side over the ARM NSA site)?

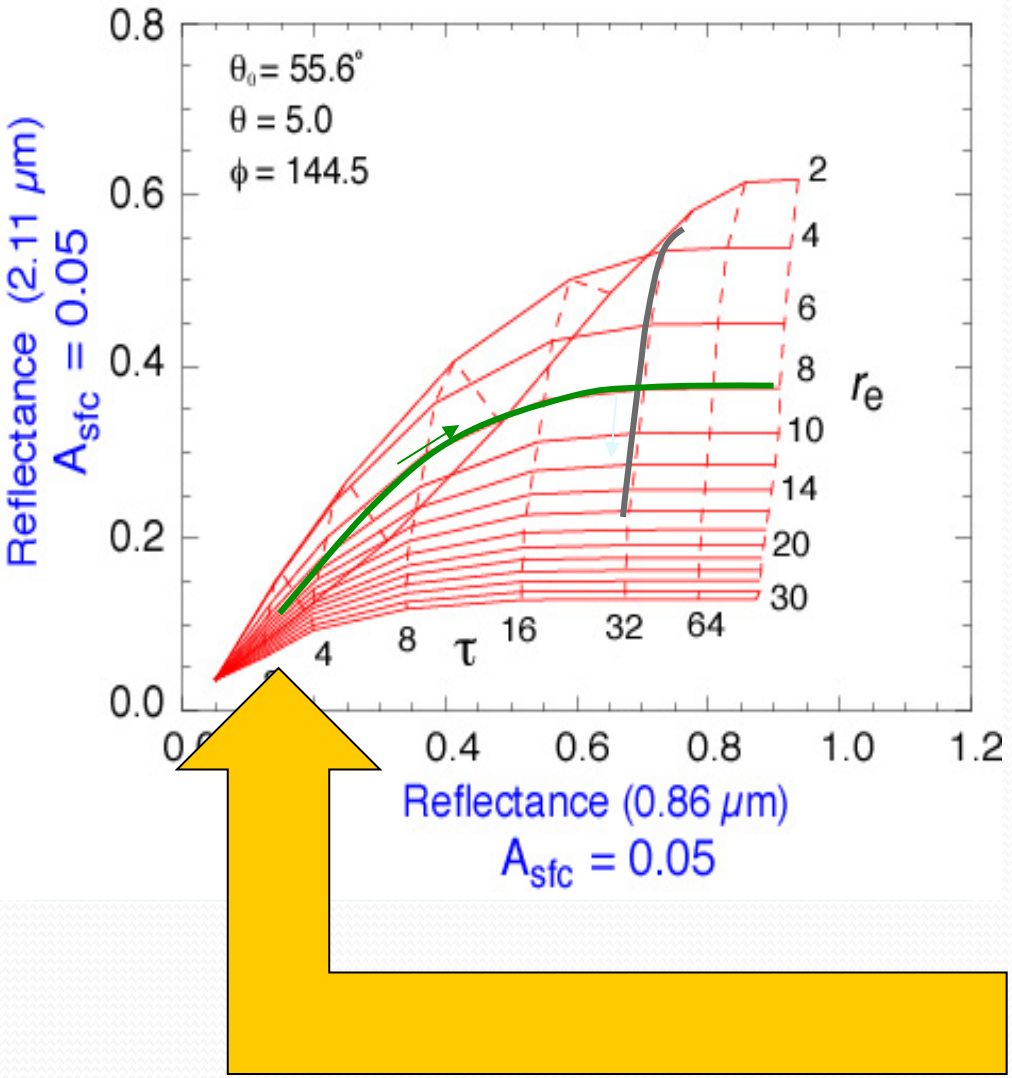
Comparisons of ARM results with CERES Ed4 and Ed2



- **Re: Ed4/Ed2 are 1.7 μm larger than ARM with no correction.**
- **Tau: Ed4 – ARM is 0.7 with R^2 =0.26, Ed2 - ARM = -5.9.**
- **LWP: Ed4 – ARM is 24 gm^{-2} with R^2 =0.13, Ed2 -ARM = 0.8 gm^{-2} due to higher re and lower tau.**

Question: Why large scatter and low R^2 values?

Satellite-retrieved r_e and optical depth over Ocean Surface R_{sfc}=0.05

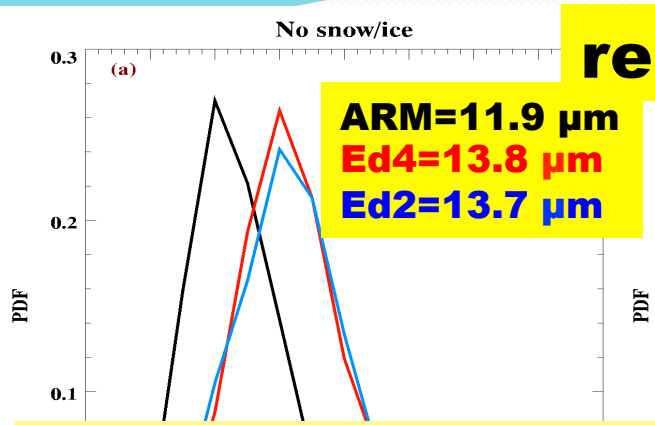


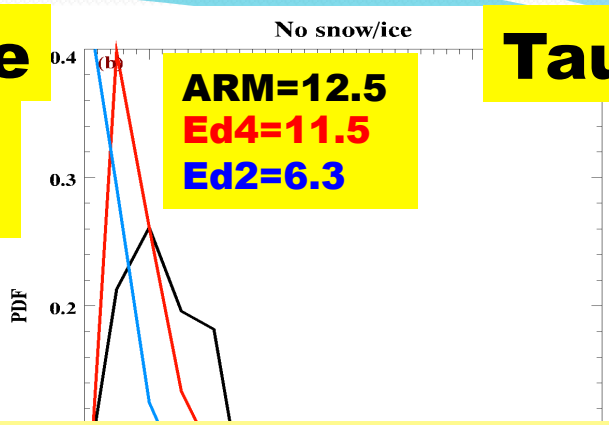
Optical depth increases with increased (λ =) 0.86 µm reflectance (X-axis)

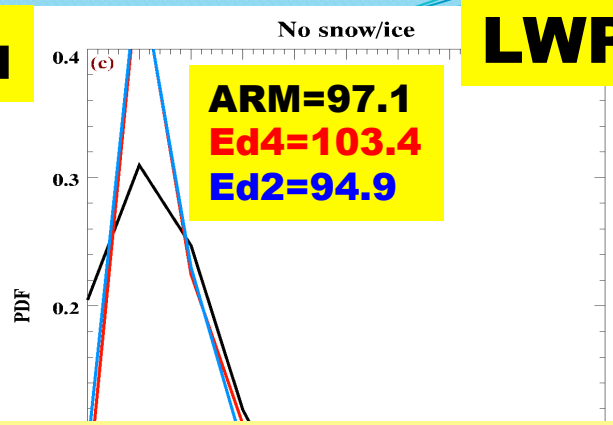
For a given optical depth, effective radius r_e increases with decreased (λ =) 2.1µm reflectance (Y-axis)

2.1 µm reflectance reaches limiting values when τ<4. Therefore, we will only compare the samples (352) with τ>4 for no-snow periods.

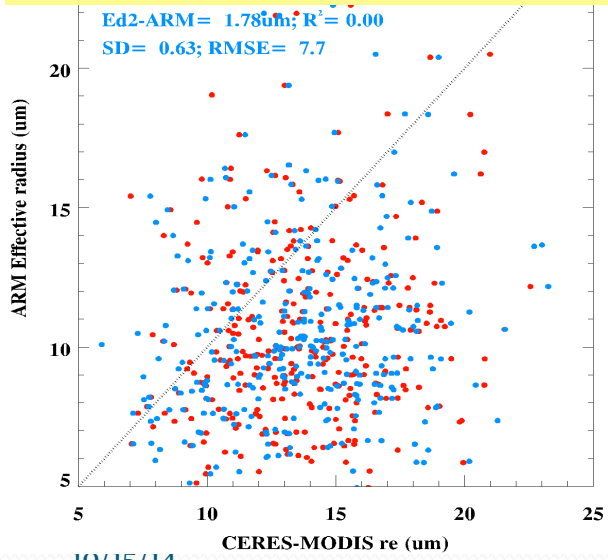
Comparisons for R_{sfc}<0.3: No Snow (352 Samples)

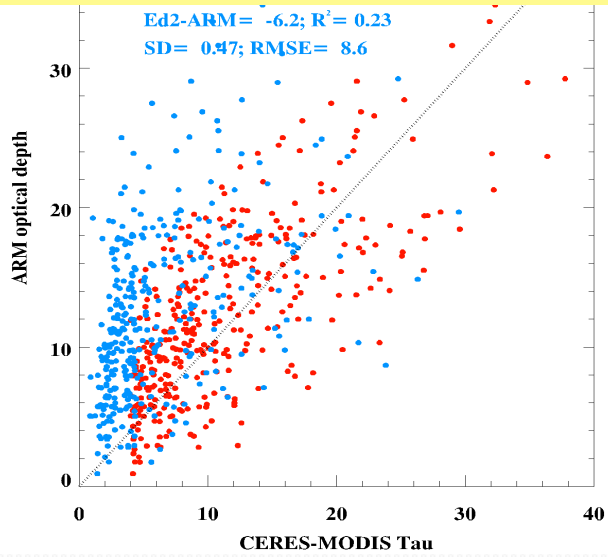


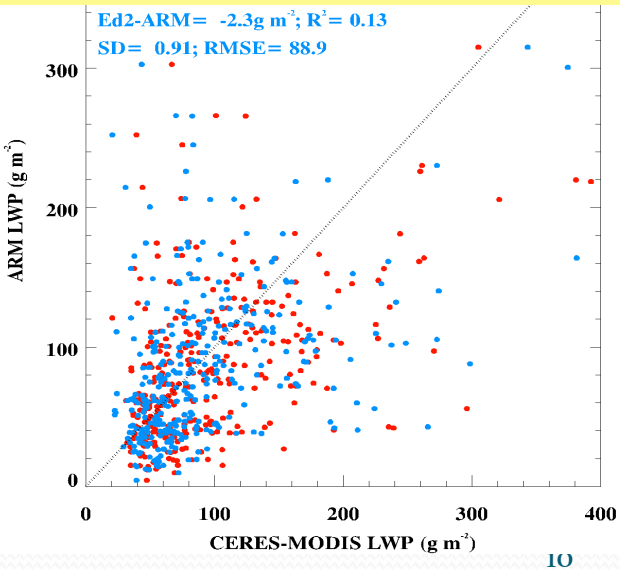




- **Re:** NO difference between Ed4 and Ed2, but they are ~1.9 μm larger than ARM retrievals.
- **Tau:** Ed4 retrievals close to ARM results, but Ed2 is only half. R^2 values increase from 0.38 (Ed2) to 0.54 (Ed4).
- **LWP:** Both Ed2 and Ed4 are within 3-6 gm^{-2} of ARM.

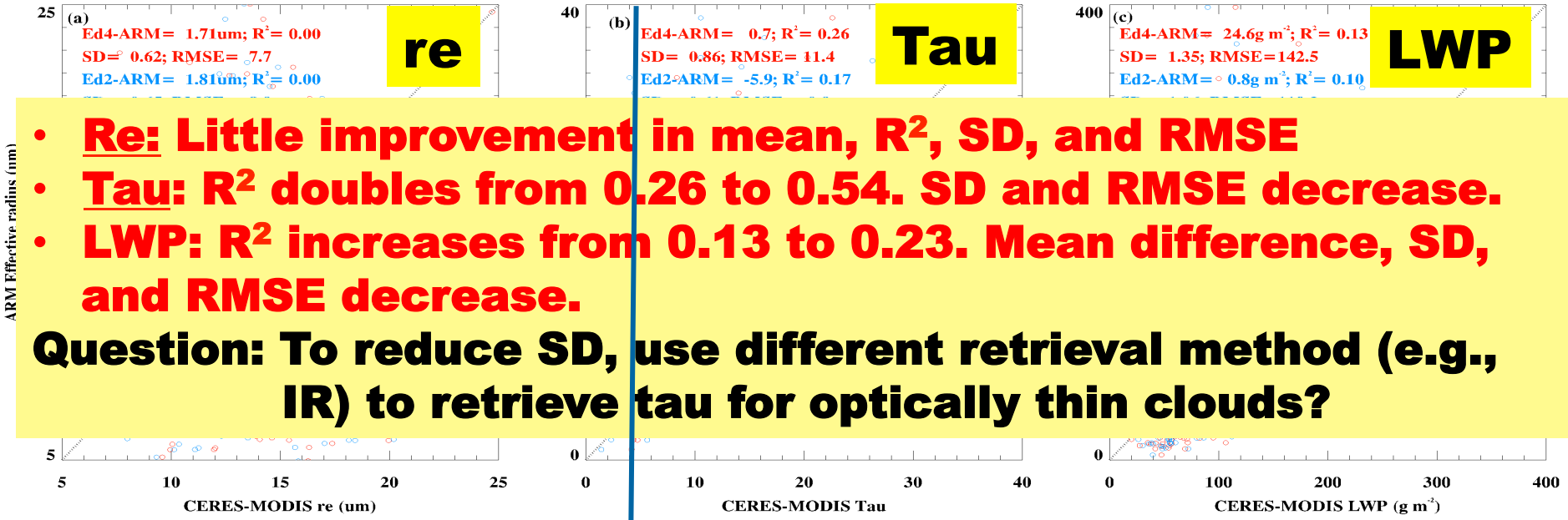






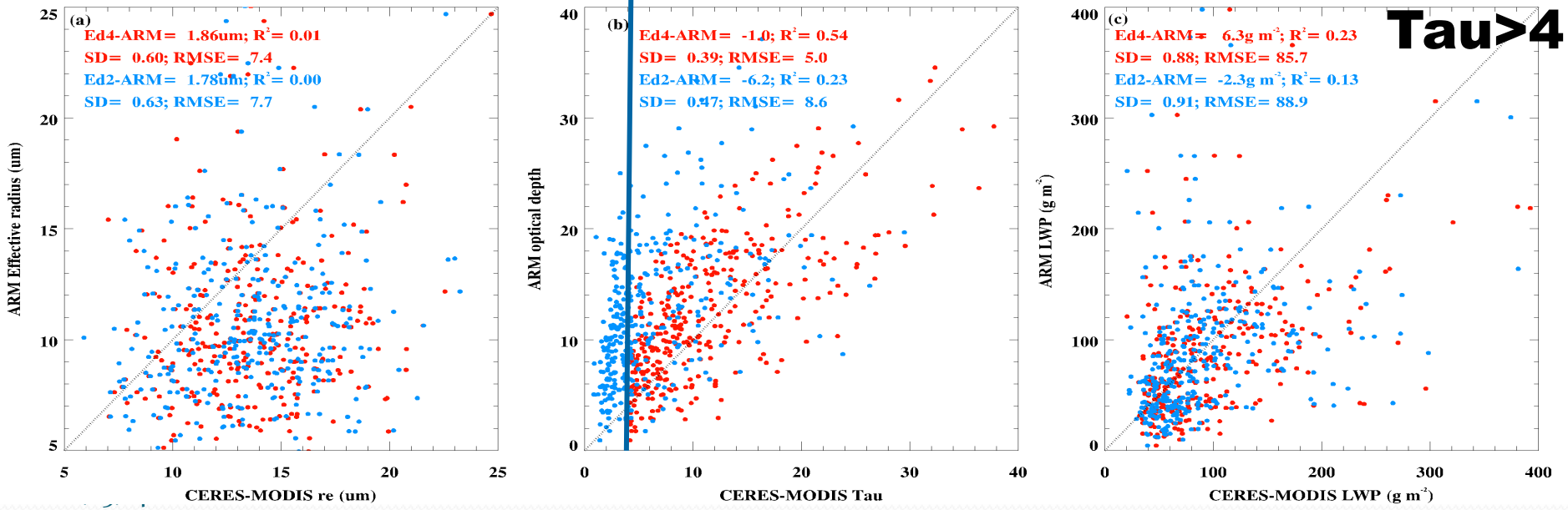
What is difference between all samples (404) and those (352) with Tau>4 (No Snow)?

All

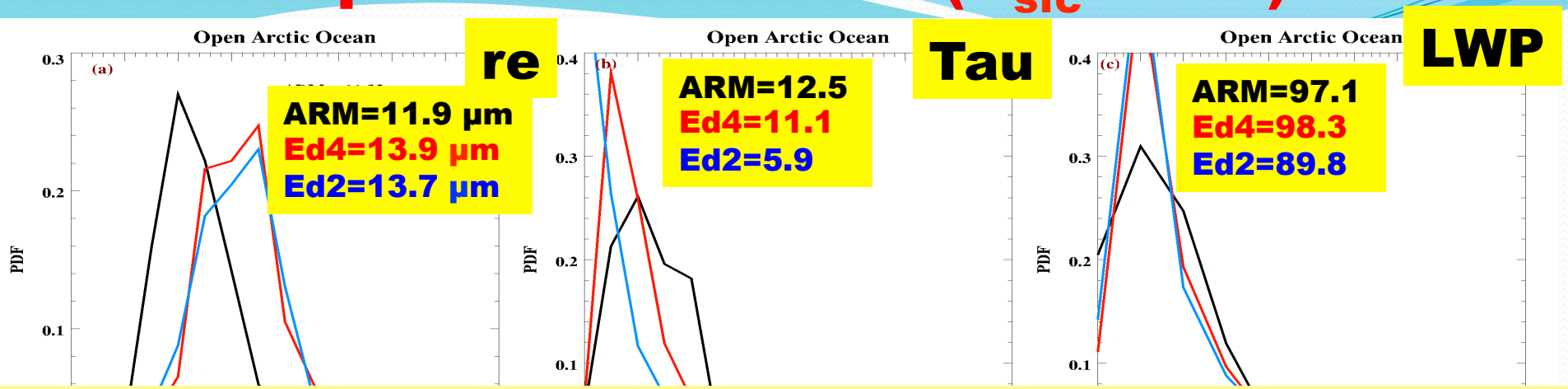


- **Re:** Little improvement in mean, R^2, SD, and RMSE
- **Tau:** R^2 doubles from 0.26 to 0.54. SD and RMSE decrease.
- **LWP:** R^2 increases from 0.13 to 0.23. Mean difference, SD, and RMSE decrease.

Question: To reduce SD, use different retrieval method (e.g., IR) to retrieve tau for optically thin clouds?



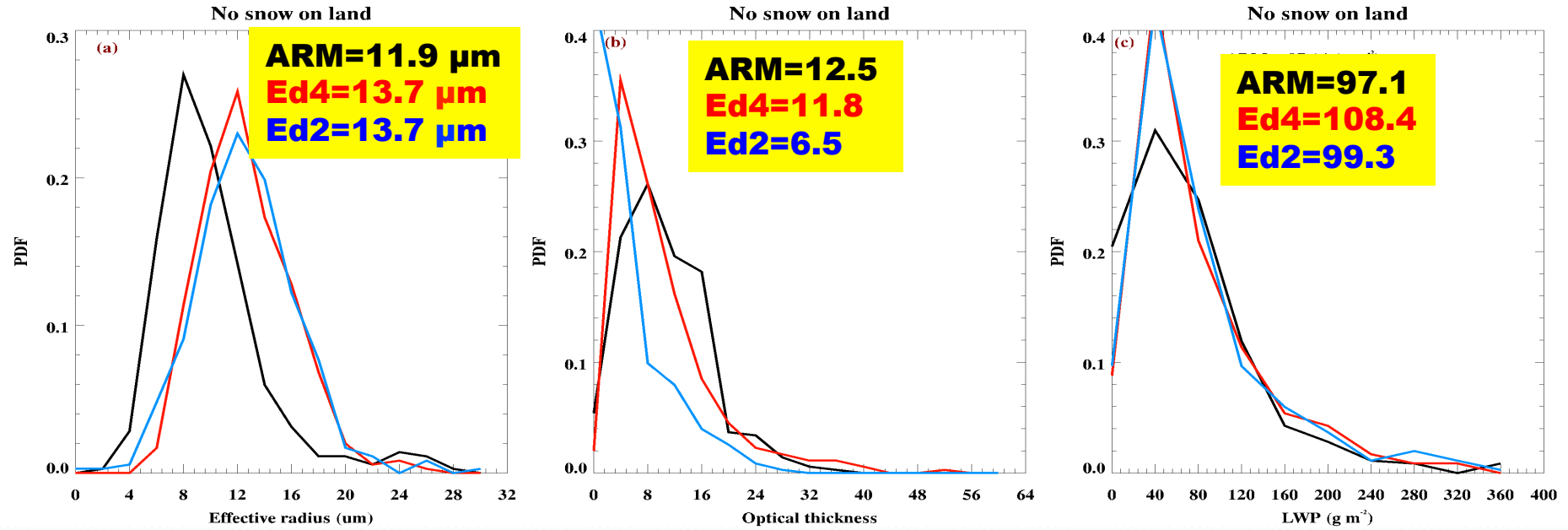
Over open Arctic Ocean (R_{sfc}~0.05)



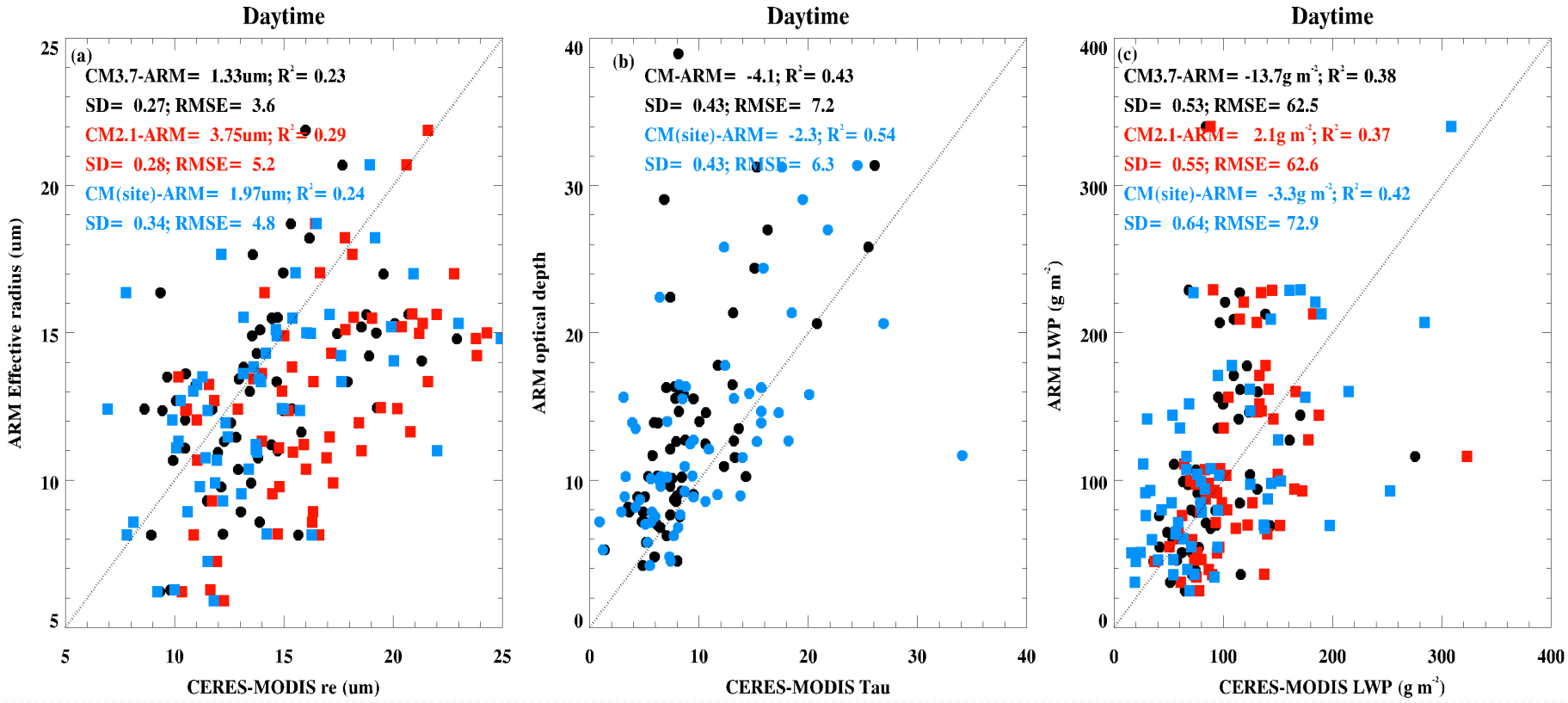
NO big differences between Ocean and Land for R_{sfc}<0.3

Summary: The re, tau and LWP comparisons are similar to the MBL cloud comparisons at the ARM Azores site (Xi et al. 2014)

Over Land side of the ARM NSA Site (R_{sfc}<0.3)



MBL cloud property Comparisons at the ARM Azores site (Ed4 only)

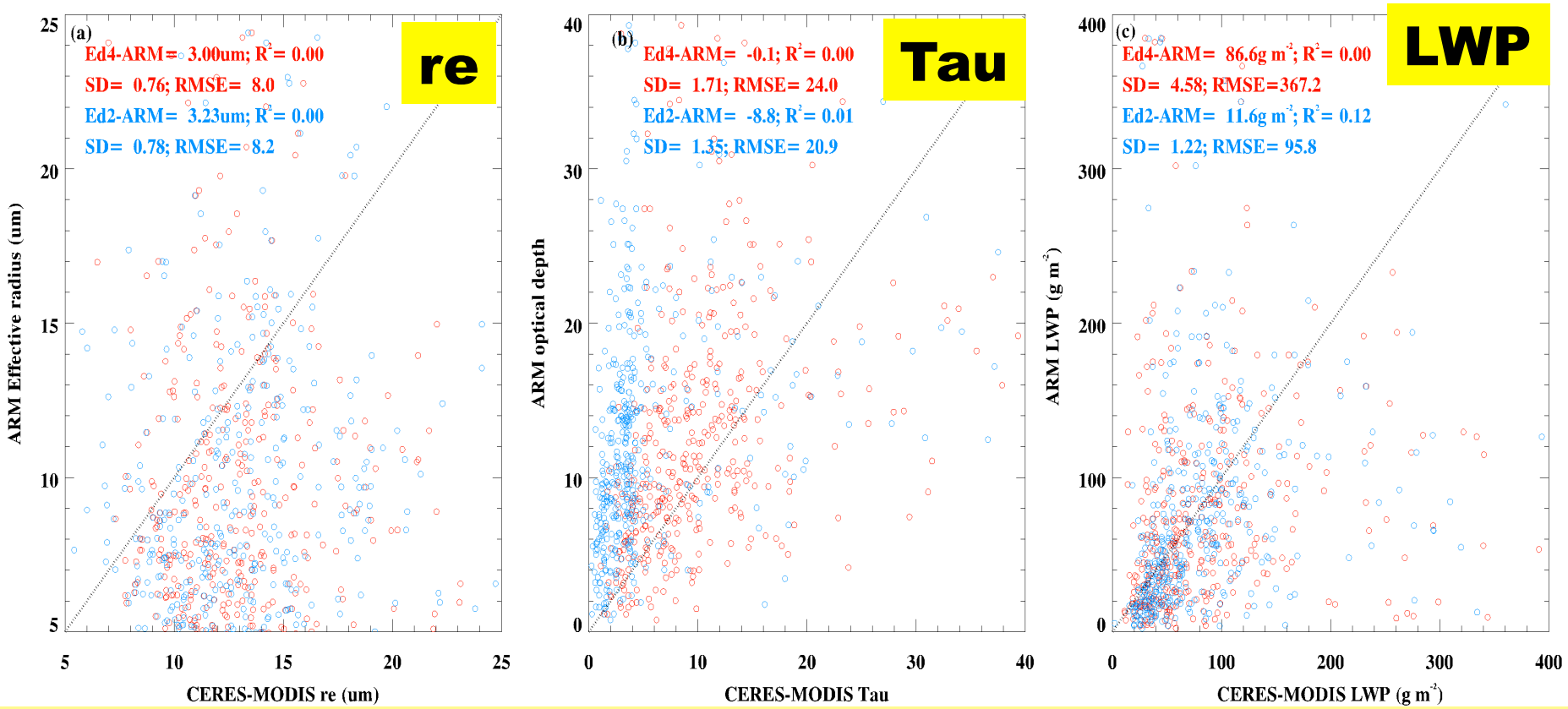


Re: ARM=12.8 μm, CM(3.7 μm)=14.1 μm, CM(2.1 μm)=16.5 μm
Optical depth: ARM=13.7, CM=9.6
LWP: ARM=114.2 gm^{-2}, CM(3.7)=100.5 gm^{-2} , CM(2.1)=116.3 gm^{-2}

Objective 2 (Snow/ice, 297 Samples)

Any differences between ARM and CERES Ed4/ Ed2 cloud retrievals over snow/ice surfaces?

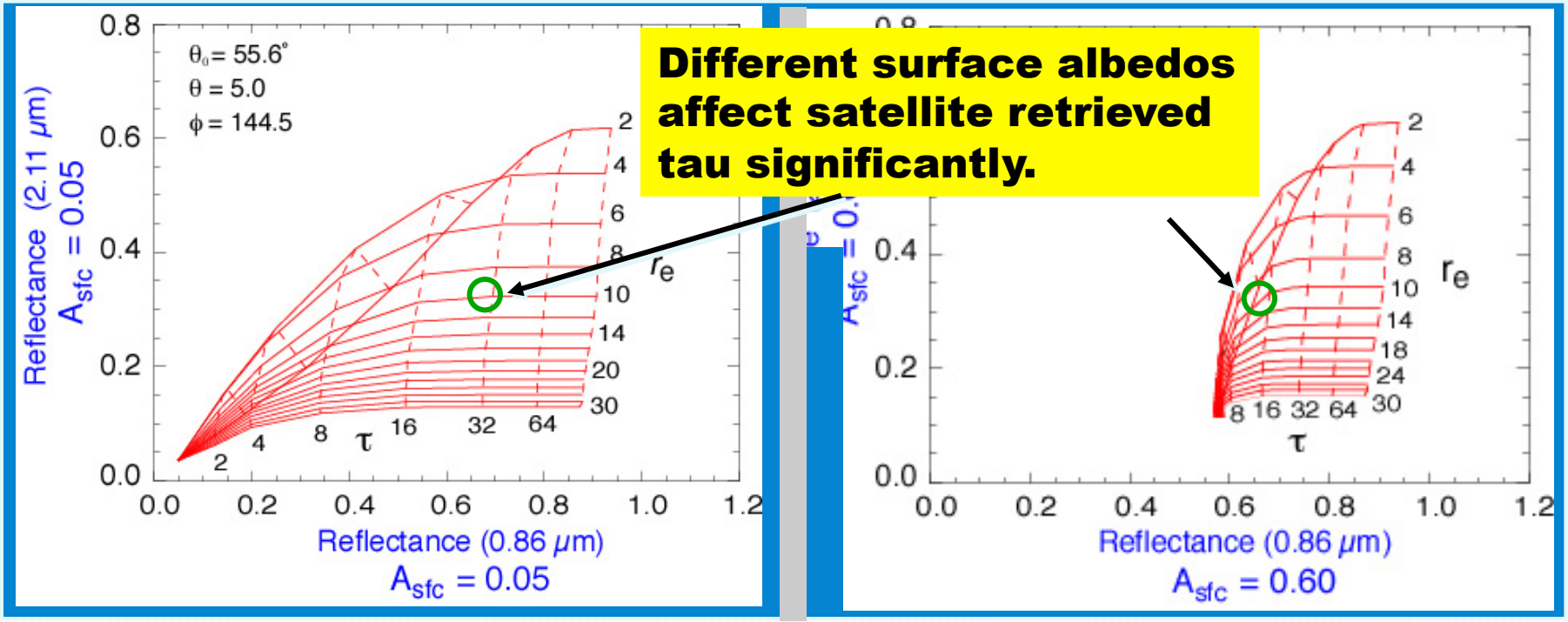
Comparisons of ARM results with CERES Ed4 and Ed2 snow surface, all samples (297)



- **Re:** Ed4/Ed2 are 3 μm larger than ARM with no correlation.
- **Tau:** Ed4 – ARM is -0.1 with R^2 =0.0, Ed2 - ARM = -8.8.
- **LWP:** Ed4 – ARM is 86 gm^{-2} with R^2 =0.0, Ed2 -ARM = 12 gm^{-2} due to higher re and lower tau.

Question: Why are the comparisons worse than NO snow ?

Satellited retrieved r_e and optical depth over snow/ice surface R_{sfc}=0.6

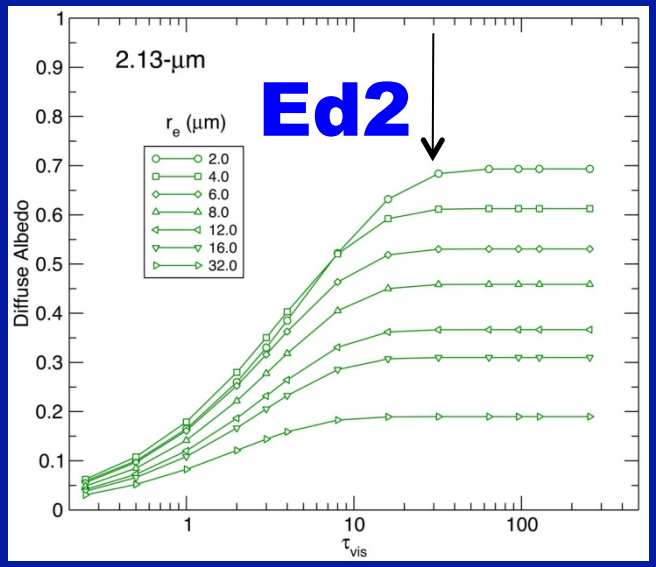


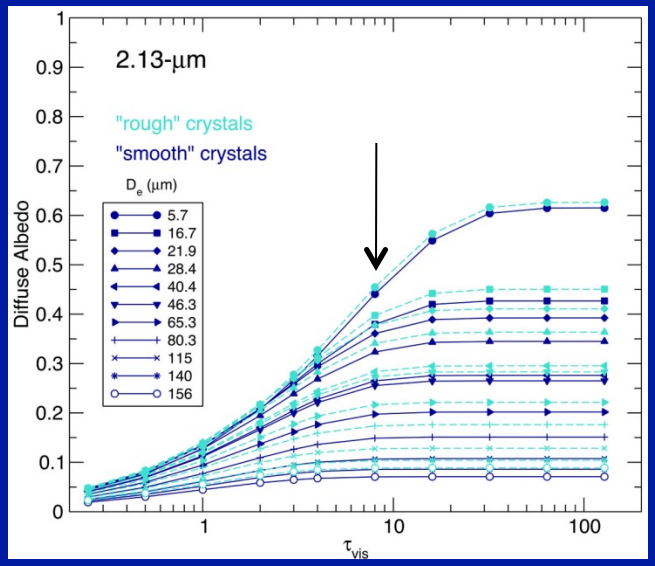
Liquid water cloud
ocean surface

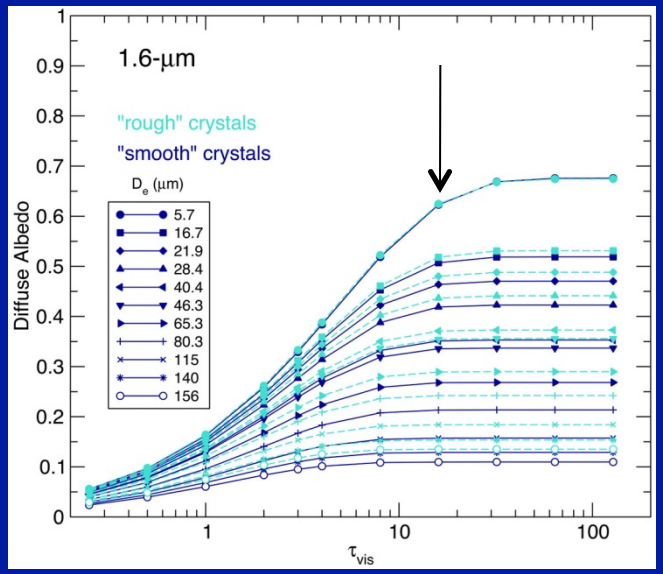
Liquid water cloud
ice surface

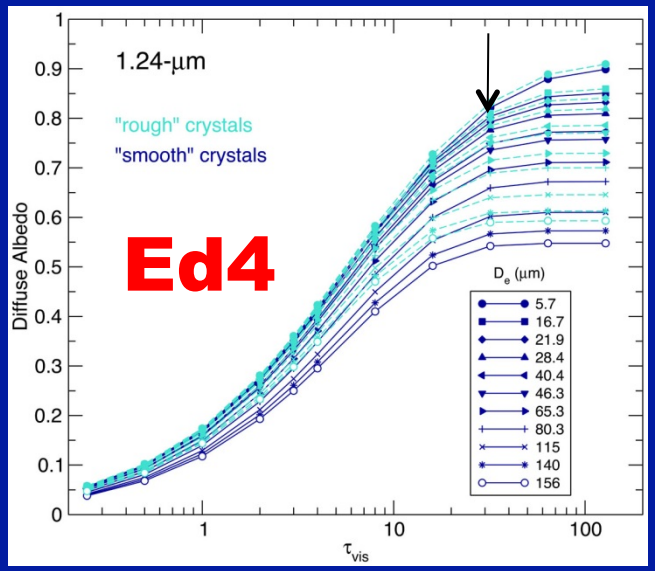
➔Given the same 0.86-um reflectance, tau at R_{sfc}=0.6 is 50% of tau at R_{sfc}=0.05, while re values only change slightly.
➔Over snow surfaces, we also use the samples with tau > 4 (252 samples) to keep consistent to NO snow comparison.

Diffuse Cloud Albedos from Adding-Doubling Computations









2.13-μm

- **Upper Limit: Tau = 16**

1.6 μm

- **Upper Limit: Tau = 16**

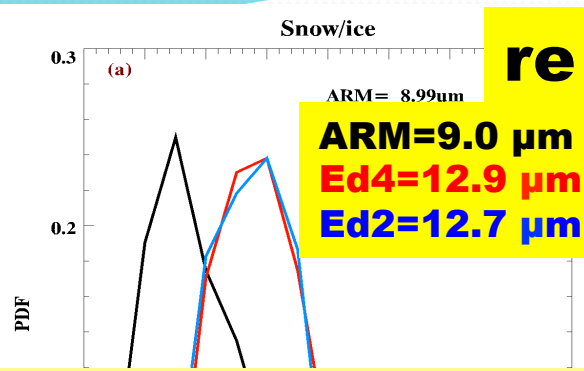
1.24 μm

- **Upper Limit: Tau > 32**

1.24 μm channel has more promise for getting most of full range of tau

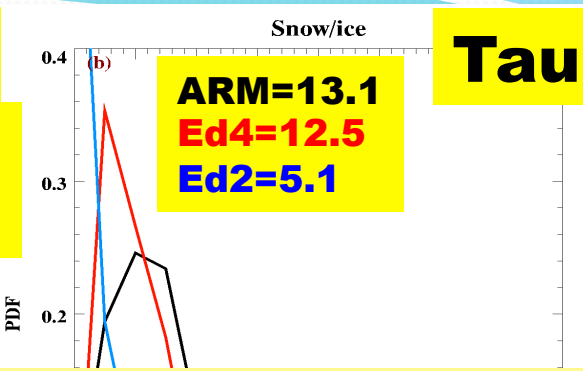
- ***MODIS team also uses 1.24 μm over snow***
- ***but still very sensitive to surface albedo***

Comparisons for R_{sfc} > 0.3: Snow/ice, tau > 4 (252 Samples)



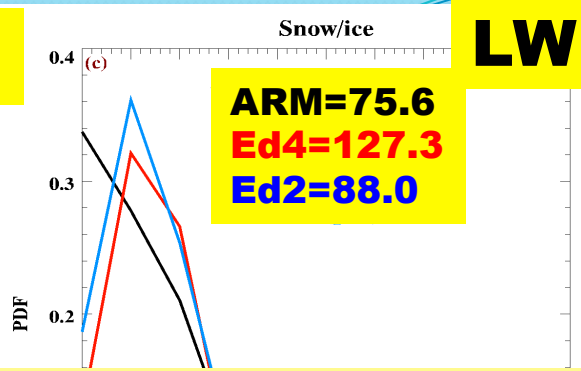
re

ARM=9.0 μm
Ed4=12.9 μm
Ed2=12.7 μm



Tau

ARM=13.1
Ed4=12.5
Ed2=5.1



LWP

ARM=75.6
Ed4=127.3
Ed2=88.0

Retrievals over NO snow surfaces:

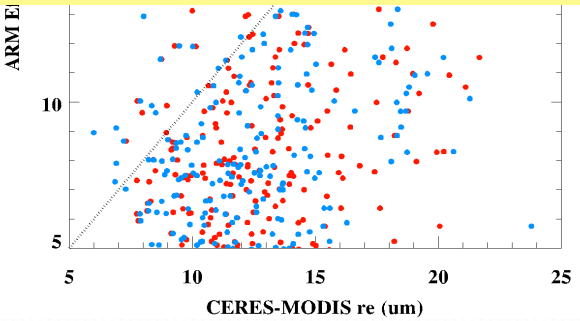
ARM=11.9 μm
Ed4=13.8 μm
Ed2=13.7 μm

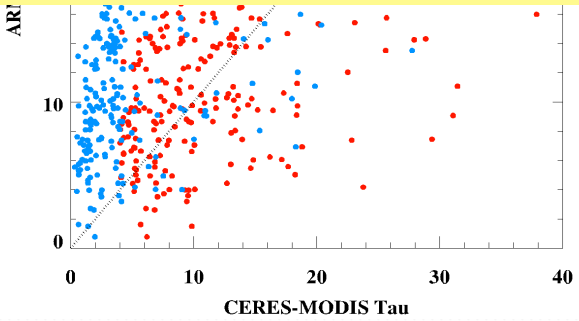
ARM=12.5
Ed4=11.5
Ed2=6.3

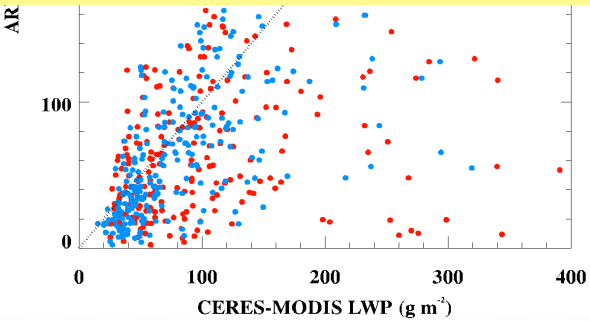
ARM=97.1
Ed4=103.4
Ed2=94.9

Compared to the corresponding retrievals without snow,

- **ARM re is 3 μm lower, tau is 0.6 higher and LWP is -22 gm^{-2}.**
- **Ed4 re is 1 μm lower, tau are 1 higher, LWP is 24 gm^{-2} more**
- **Over snow, ΔTau(Ed4 – ARM)= -0.6, but ΔRe(Ed4/Ed2 – ARM) = 3.9 um, doubled the difference for no snow, resulting in ΔLWP(Ed4 – ARM)= 51 gm^{-2}.**







Difference between all samples & tau >4 (Snow)

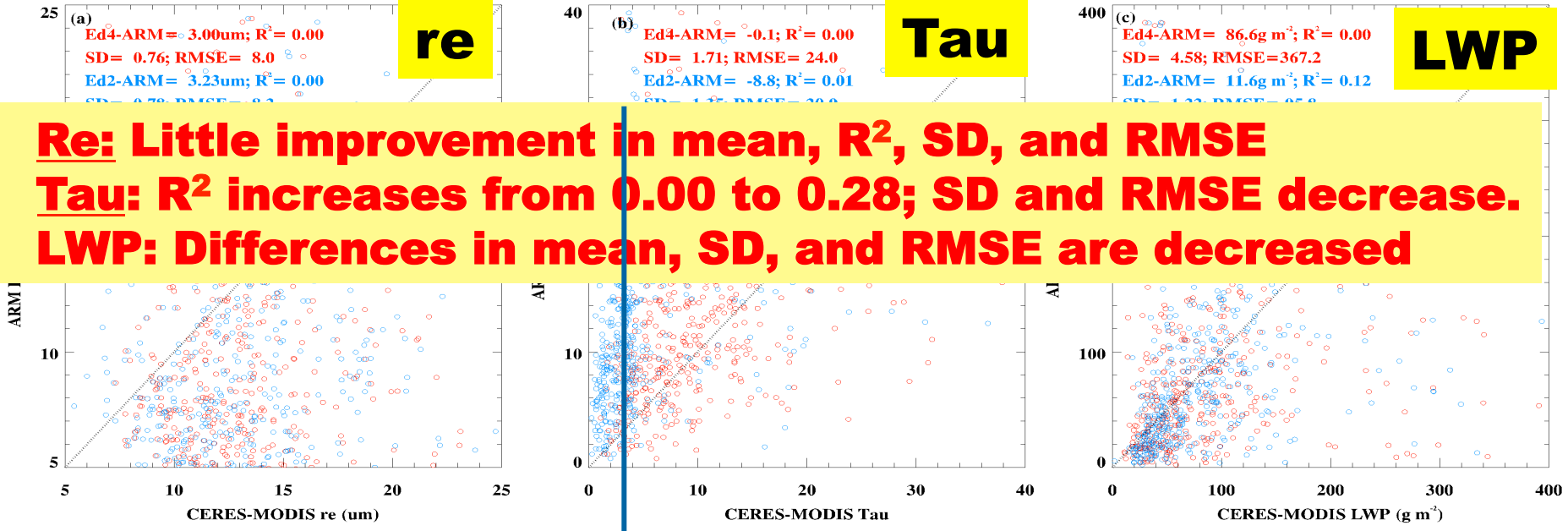
All

re

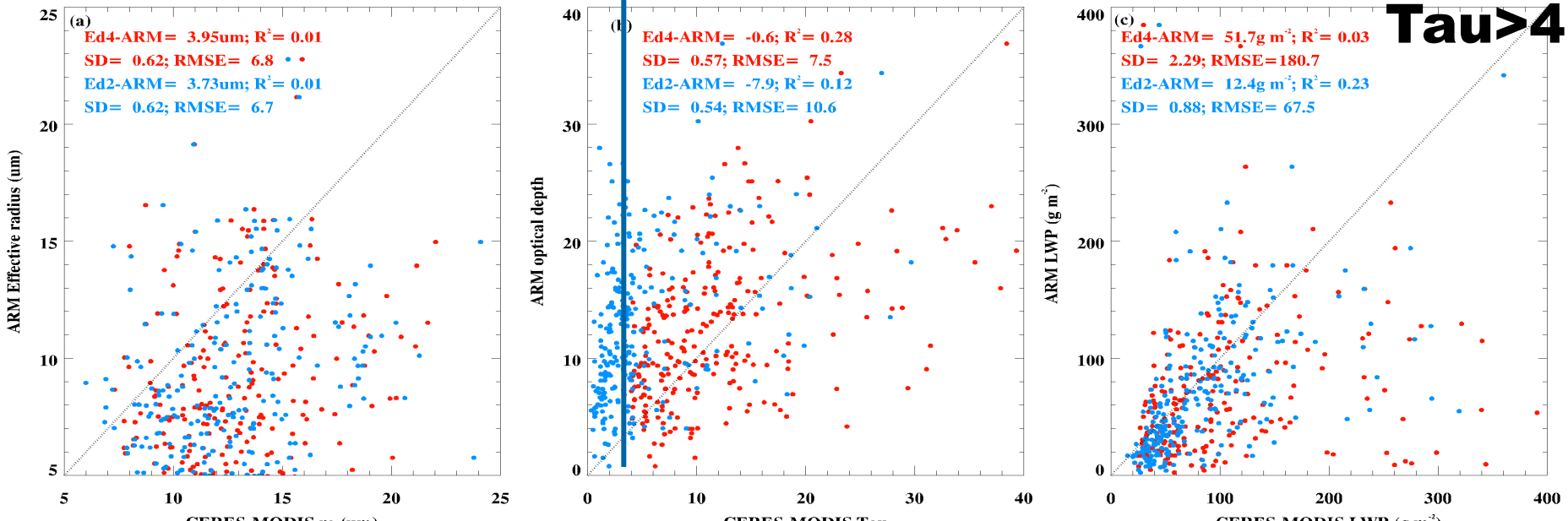
Tau

LWP

- **Re: Little improvement in mean, R^2, SD, and RMSE**
- **Tau: R^2 increases from 0.00 to 0.28; SD and RMSE decrease.**
- **LWP: Differences in mean, SD, and RMSE are decreased**

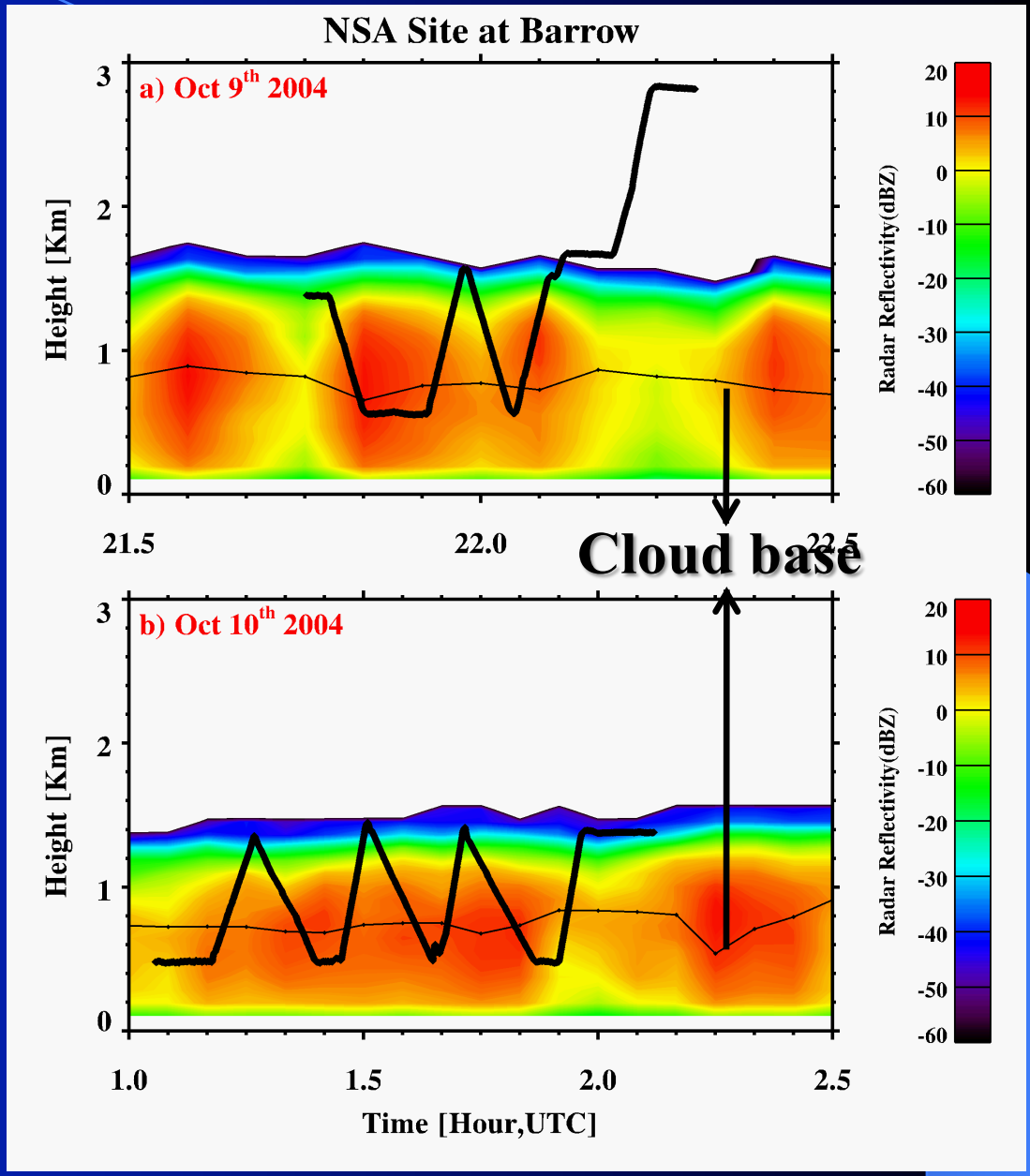


Tau>4



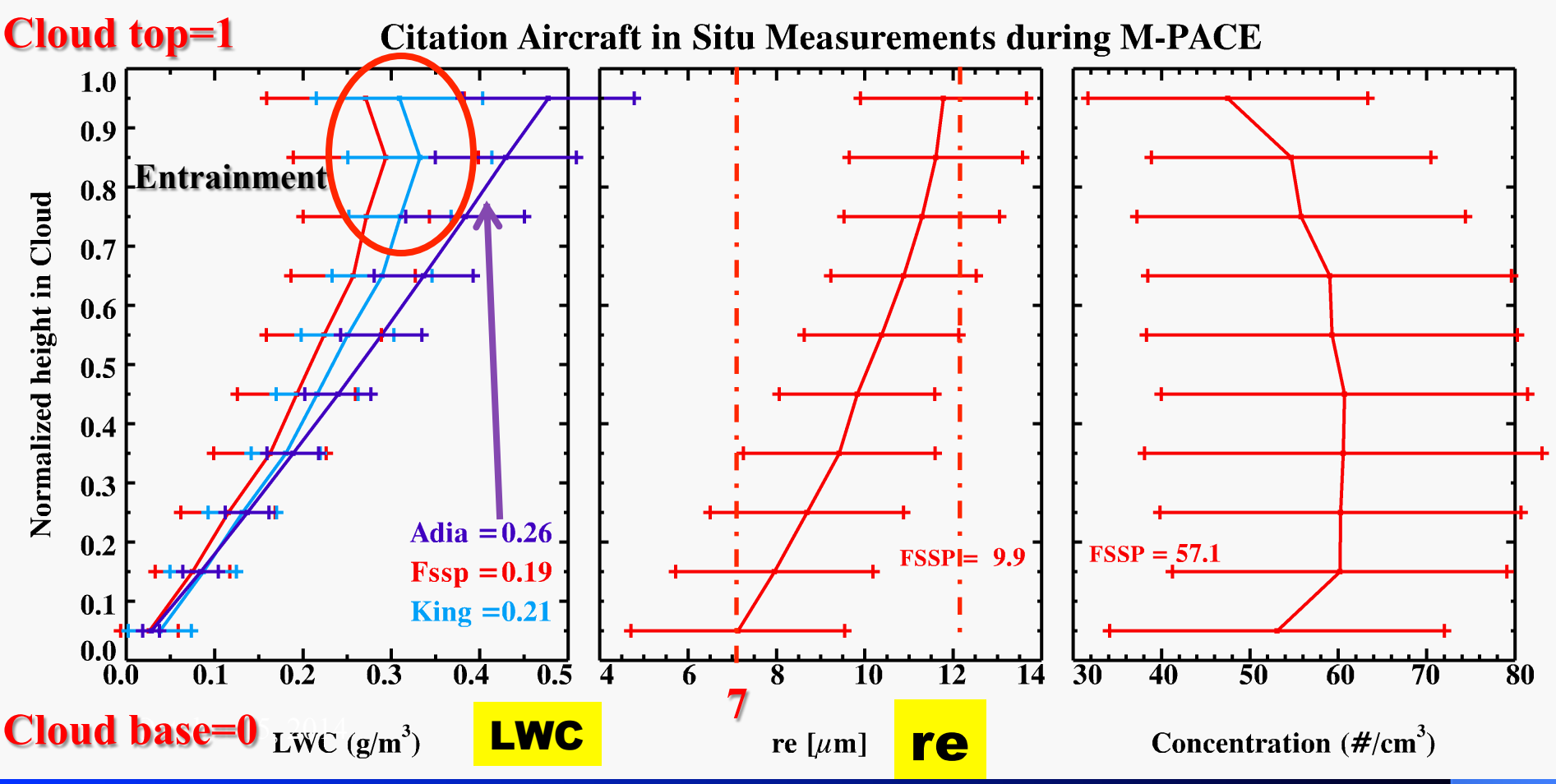
In-Situ Measurements during M-PACE (10/2004)

- Combine MMCR and in-situ data
  - Fly over a certain distance away from Barrow site
  - MMCR cloud top slightly higher than in-situ data
  - 11 vertical profiles
    - 4 on 9 October
    - 7 on 10 October

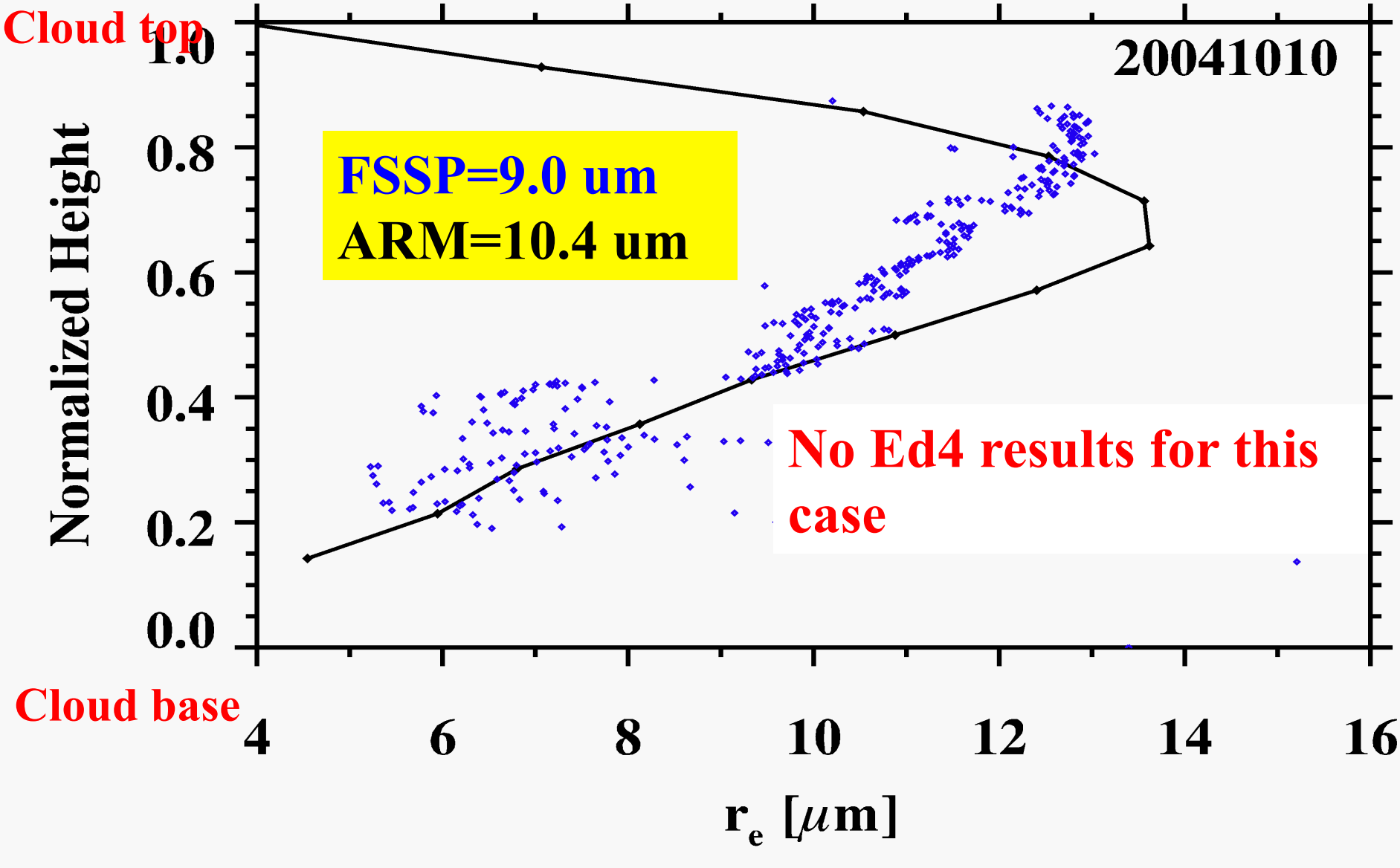


Aircraft In-Situ Measurements

- **Liquid phase properties**
  - Two main probes: FSSP and King



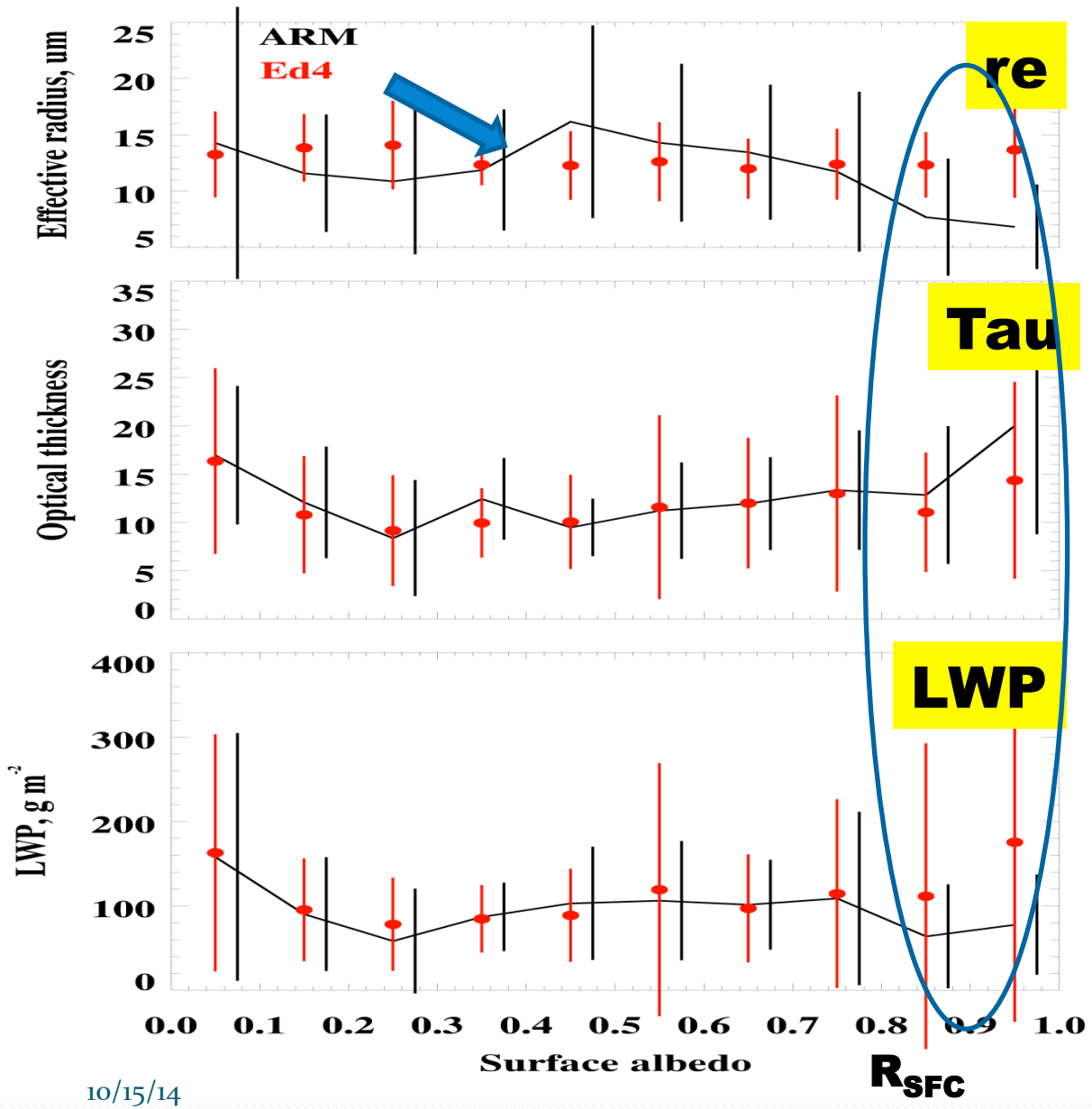
ARM LWC and Re retrievals agree well with aircraft in-situ data



Objective 3
(604 samples for tau>4)

How do the surface and CERES-MODIS retrieved cloud properties change with surface albedos and solar zenith angles?

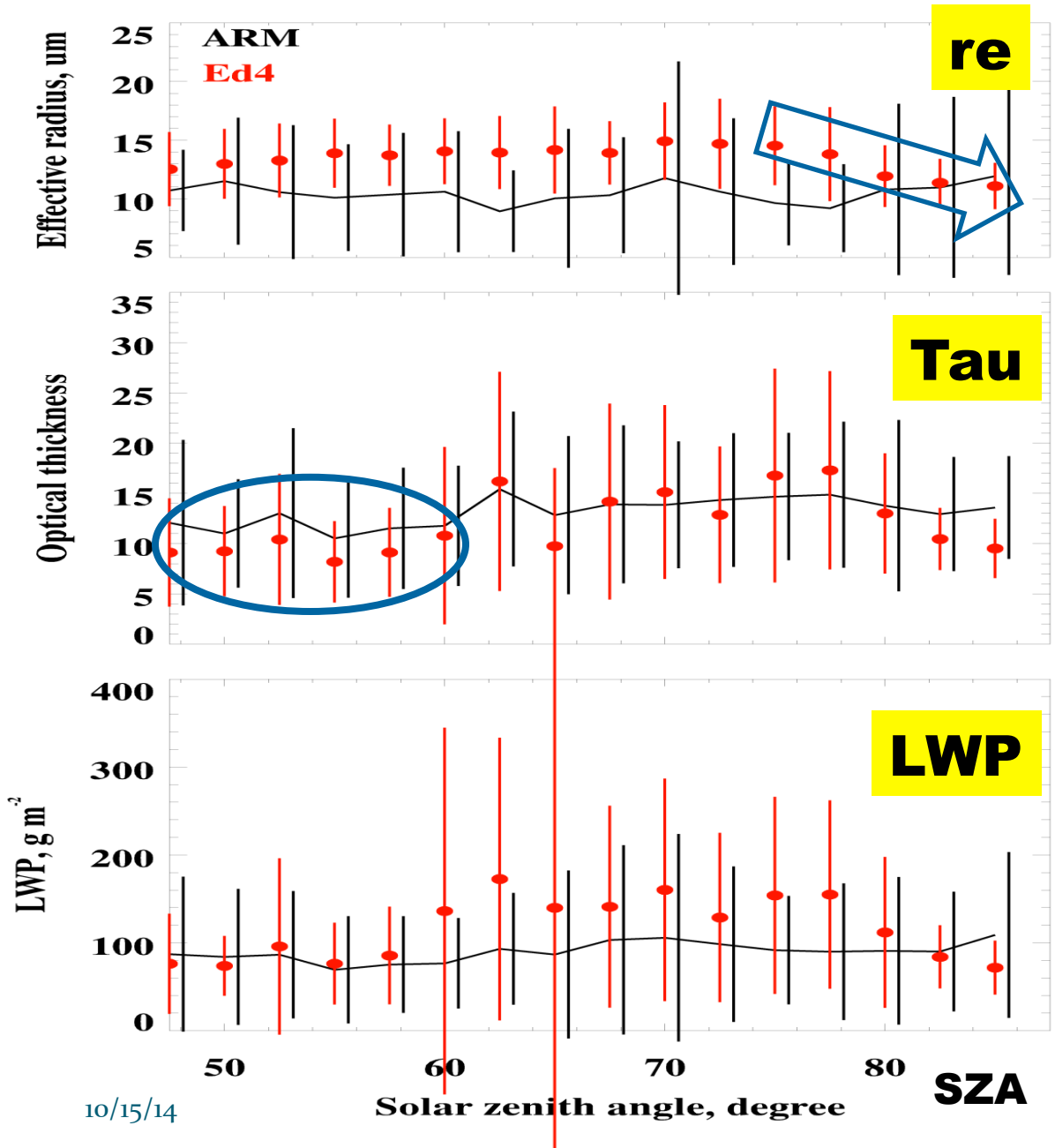
Re, tau and LWP vs. Surface Albedos



→ARM retrieved re values follow LWP variations, peaks at R_{SFC}=0.4-0.5, then decreases with R_{SFC}.
→Ed4 decreases at R_{SFC}=0.3.
→ Δre(Ed4 – ARM) is larger when R_{SFC} >0.8

Both ARM and Ed4 tau (and LWP) agree very well, and almost independent on surface albedo except for R_{SFC}>0.8.

Re, tau and LWP vs. Solar Zenith Angles



Same as ARM LWP, ARM re values do not change with SZA. Ed4 re is also independent on SZA, but decreases at SZA>75°.

ARM tau is also invariant to SZA, but Ed4 tau values are lower than ARM at SZA<60°, after that they fluctuate around ARM values.

Summary and Conclusions (1)

Retrievals without snow (R_{sfc}<0.3):

Re: ARM=11.9, Ed4=13.8, Ed2=13.7

Tau: ARM=12.5, Ed4=11.5, Ed2=6.3

LWP: ARM=97.1, Ed4=103.4, Ed2=94.9

Retrievals with snow (R_{sfc}>0.3):

Re: ARM=9.0, Ed4=12.9, Ed2=12.7

Tau: ARM=13.1, Ed4=12.5, Ed2=5.1

LWP: ARM=75.6, Ed4=127.3, Ed2=88.0

1) Compared to ARM retrievals, there is significant improvement in optical depth from Ed2 to Ed4, while their re values are almost the same.

2) The cloud comparisons between ARM and Ed4 without snow are best (Corr=0.74), they are similar to the MBL comparisons at the ARM Azores site.

3) Over snow, the difference in re between ARM and Ed4 is double those without snow, while tau difference is same.

Summary and Conclusions (2)

4) Impact of surface albedo on cloud properties:

- **There are almost no impact on optical depth and Ed4 re retrievals, but ARM retrieved re values follow LWP variations, decreases with R_{SFC} when R_{SFC}>0.5,**
- **Differences in re, tau and LWP between ARM and Ed4 rise & correlations smaller when R_{SFC} >0.8 → Need further study.**

5) Impact of Solar Zenith Angle (SZA) on cloud properties:

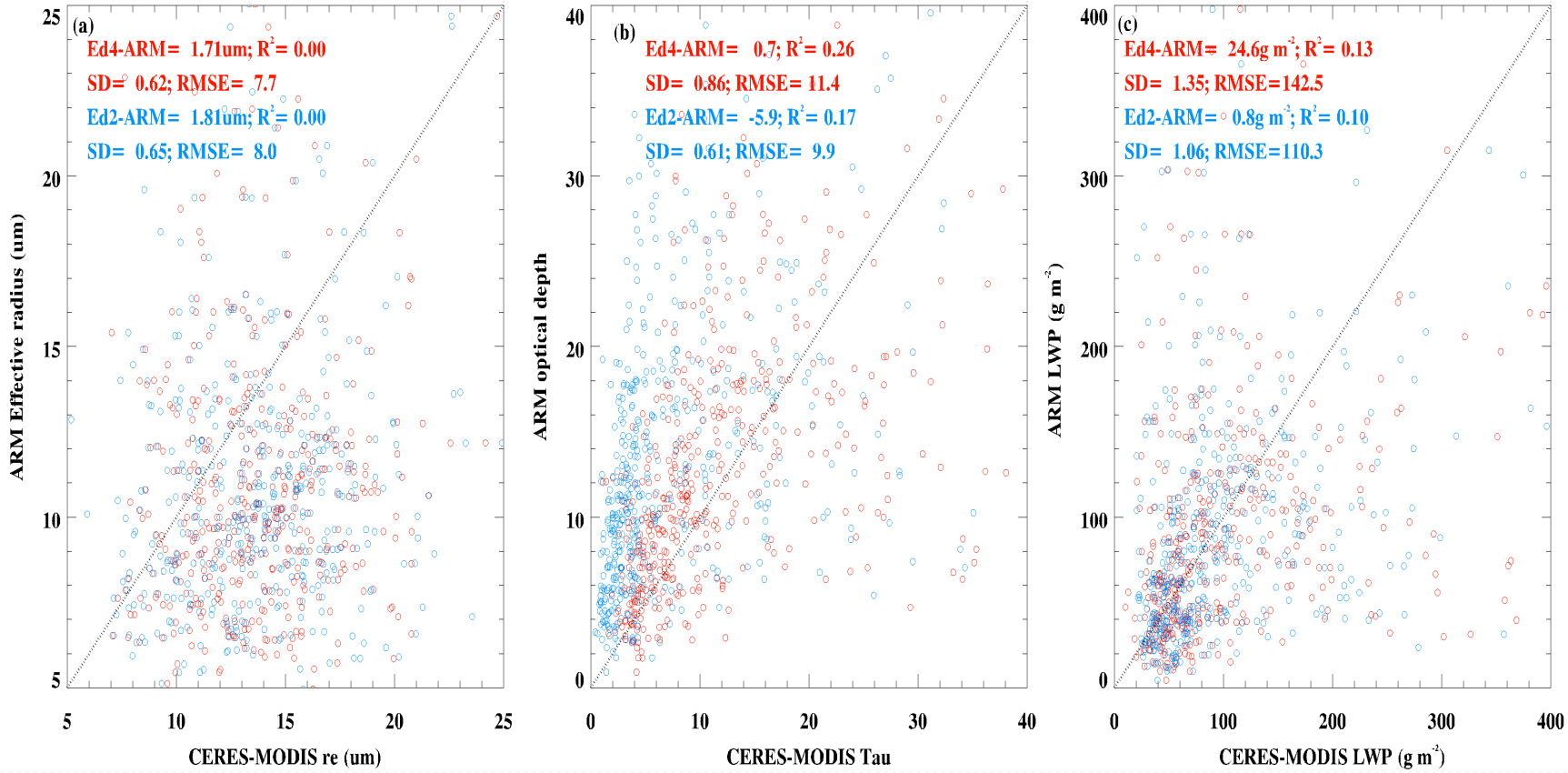
- **ARM retrieved re, tau and LWP, as well as Ed4 re are invariant with SZA, while Ed4 tau values are lower than ARM ones at SZA<60°.**

Thanks for your attention!

A big challenge for both Surface and satellite to retrieve cloud properties with high SZA and surface albedo

Comparisons for R_{sfc}<0.3: No Snow (404 Samples, no Tau< 4 threshold)

re **Tau** **LWP**



Comparisons for R_{sfc} > 0.3: Snow/ice (169 Samples)

Retrievals without snow:

Re: ARM=11.9, Ed4=13.8, Ed2=13.7, R^2=0.01, R^2=0.00

Tau: ARM=12.5, Ed4=11.5, Ed2=6.3, R^2=0.54, R^2=0.23

LWP: ARM=97.1, Ed4=103.4, Ed2=94.9, R^2=0.23, R^2=0.13

Compared to the retrievals without snow,

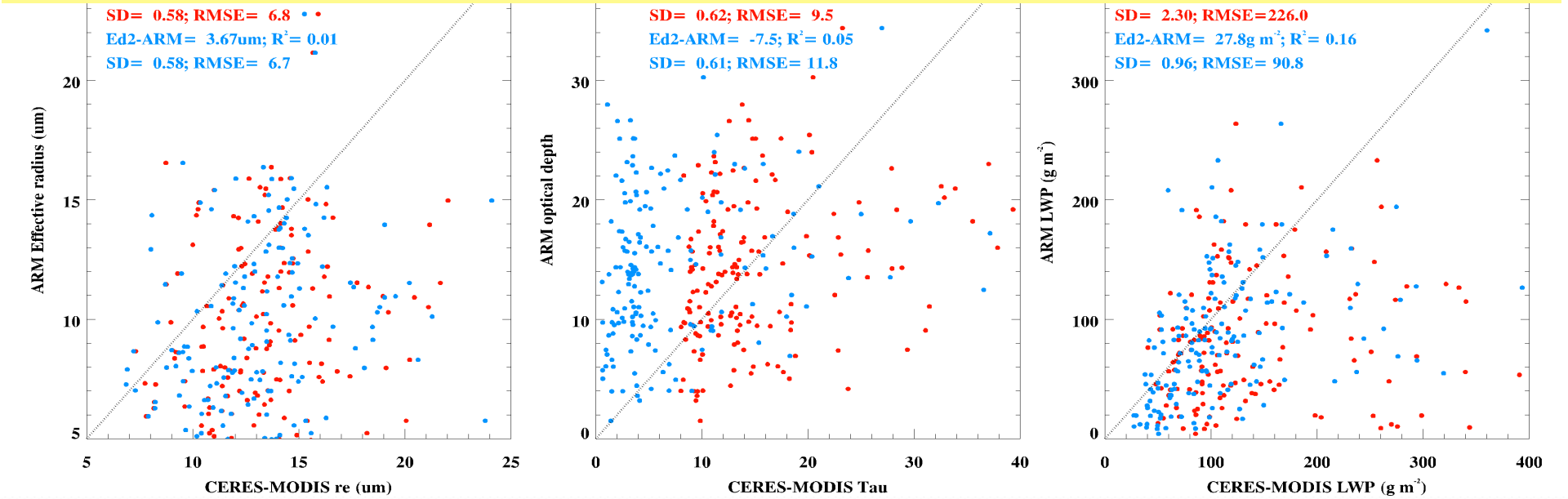
- **ARM re is 2 μm lower, while CM Ed2 and Ed4 are same.**

The differences between ARM and Ed4/Ed2 is doubled.

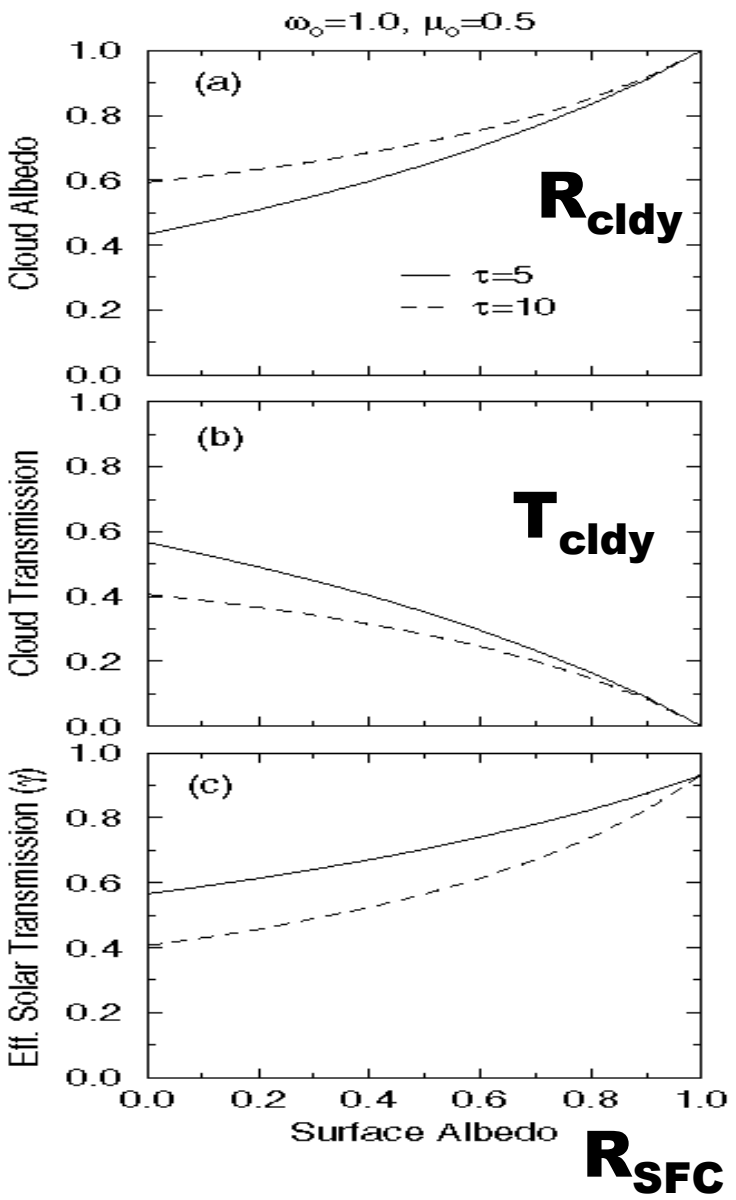
- **ARM tau is 2.4 higher, Ed4 is 5.4, and Ed2 is 1.1 with lower R^2**

The difference between ARM and Ed4 is 2, also doubled.

- **ARM LWP is -7 gm^{-2}, but Ed4 is doubled ARM LWP.**



The effect of surface albedo R_{sfc} on the retrieval of Arctic cloud microphysical properties (Dong and Mace 2003)



For non-absorbing clouds, due to multiple reflections between cloud layer and reflecting surface,

(a) Cloud albedo increases and (b) cloud transmission decreases with increased R_{sfc}.

R_{sfc} becomes dominant for R_{sfc}>0.6.

(c) For the ARM PSP (0.3-3 um) measured effective solar transmission (γ), which is used in our ground-based retrieval algorithm, increases as R_{sfc} increases due to multiple reflections between surface and cloud layer.

- $re = -1.496 + 2.49\,LWP + 10.25\gamma(1-Rsfc3) - 0.25\,\mu 0 + 20.28\,LWP\gamma(1-Rsfc) - 3.14\,LWP\mu 0$